'Re-making the nation', uses and recycling of brick in medieval English buildings: insights from the application of luminescence dating and new avenues for further research.

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SUMMARY

Luminescence dating has been applied to ceramic bricks sampled from a selection of English medieval ecclesiastical and secular buildings in Essex, Kent and Lincolnshire, ranging in age from the fourth to the late sixteenth centuries. The results obtained for the Anglo-Saxon churches, which included Brixworth, confirmed the re-use of Roman brick in all cases. The dates for the earliest medieval brick type indicate that brick making was reintroduced during the eleventh century, a century earlier than previously accepted, and dates for Tudor bricks from the same secular vernacular building indicate that the practice of recycling of building materials during the late medieval period was also applied to brick.

INTRODUCTION

While documentary evidence and stylistic assessment can potentially provide the basis for precisely dating medieval buildings in England, this approach is usually restricted to a relatively small number of high status structures of a specific function such as early and late medieval churches, cathedrals, palaces and castles. For most vernacular buildings, documents relating to a particular construction phase are frequently missing, or never existed, and the evidence available for dating is open to interpretation. In such cases additional methods are required to obtain reliable dating. This can be achieved by testing roof and structural timbers using dendrochronology, a method that has the capability to precisely date the construction of medieval structures providing the timbers associated with the primary construction survive and can be shown themselves to have been created within a primary phase of building and not recycled or reused from other structures. However, its application in eastern England, where most of the medieval brick building was initiated, has been limited by problems related to the occurrence of fast growing trees that can lead to difficulties in matching to regional master chronologies (Pearson, 1997). In addition, a tendency in English vernacular building traditions to recycle timber from preceding structures adds further complications in terms of establishing primary and secondary construction phases using dendrochronology

An alternative approach in the case of buildings built in brick or containing ceramic building materials (CBM) is the luminescence method. This approach has already been applied sporadically since the 1970s to the dating of bricks in medieval and early modern buildings in England (Cramp et al, 1977; Bailiff and Holland, 2000; Antrobus, 2004; Bailiff, 2007) and also in Europe (Goedicke et al., 1981; Jungner, 1987; Abrahamsen et al.,1998; Čechak et al., 2000; Hütt et al., 2001; Göksu and Schwenk, 2001; Martini and Sibilia, 2001; Blain et al., 2007; Chruścińska et al, 2008; Sapin et al, 2008). This paper presents the results from a combined project designed to test if luminescence dating could be applied successfully to English medieval buildings containing CBM within their build, as a means of refining known chronologies by dating hitherto imprecisely dated and phased structures, and also addressing questions of the use and reuse of ceramic materials in their construction. In particular, we wished to explore whether the method has the potential to produce chronological data that provide a means of critiquing current understanding of vernacular building traditions and the social implications of sourcing and using CBM as a material in such constructions. Evidence for the reuse of Roman brick in the early medieval period is widespread in buildings of the Anglo-Saxon period (c. AD 600-1100?) and it is currently accepted that this practice continued in England until brick manufacture resumed in the mid-twelfth century (Eaton, 2000; Salzman 1967, 140). With the exception of a small number of documented cases (e.g., Simpson, 1960), it is generally assumed that buildings were constructed with new brick once the craft of brickmaking had been reintroduced (Moore, 1991). However, as with masonry (Parsons 1990; 1991; Stocker 1990; Morris 2003) and timber (Clifton-Taylor 1987, 300), dating information can allow questions of recycling and reuse of brick in medieval building practice to be addressed as part of the wider enquiry into sustainable traditions of the medieval economy and industry (Blair and Ramsey 1991).

Since the number of brick buildings tested in England to date has been limited, a geographically and temporally broader range of buildings was chosen for examination and tested via three separate

studies. This work encompassed two doctoral projects, one including the examination of Roman *spolia* in a selection of early medieval ecclesiastical buildings in Kent and Essex (Blain, 2009) and the second focused on the dating of later ecclesiastical and secular brick buildings in Essex built between the eleventh and the sixteenth centuries AD (Gurling, 2009). In a third study the dating of brick from the important early church of All Saints, Brixworth, which was the subject of the first application of thermoluminescence (TL) to brick dating reported in Cramp et al. (1977), was re-examined (Bailiff 2006). These studies were preceded by a programme of testing buildings with independent dating control, the results of which are summarised below but appear in full in a separate technical methodological paper (Bailiff 2007).

BRICK TYPES IN ENGLISH MEDIEVAL BUILDINGS

Following the collapse of the Roman Empire, the manufacture of CBMs such as bricks and tiles continued, albeit to a limited extent, within NW Europe in the Low Countries and in France (Perlich, 2008). This has also been confirmed by recent luminescence dating studies of ecclesiastical buildings in NW France (Blain et al. 2007; Sapin et al. 2008). In contrast, brickmaking in England is considered not to have resumed until the middle of the twelfth century (Smith 1985, 2). Surviving ecclesiastical buildings constructed in the early medieval period nonetheless contain brick as dressings for quoins, window and door apertures and in the fill of flint rubble walls, and these are generally accepted to be Roman *spolia*. Evidence of the earliest known local use of medieval brick is found in late medieval buildings in Essex (Clifton-Taylor 1987, 211; Wight 1972, 374; Ryan 1996), in the form of 'great bricks' made on a one foot module (predominantly falling within the ranges 290-380 by 145-195 by 32-90 mm) which are larger than Flemish type bricks (220-35 by 110 by 50-60 mm). Notably, the distinctive Coggeshall type bricks (320-30 by 150-60 by 40-50 mm), which are named after their use at Coggeshall Abbey, built in ca 1160, are considered to be the earliest of the great bricks, but may have been used in buildings constructed earlier in the twelfth century (Rodwell 1998, 103; Andrews 2005, 142; 2008, 59). The Coggeshall type bricks, which included various moulded forms, were made for a limited period and are found in buildings located within a restricted region of Essex, although similar bricks have been identified in a small number of buildings further afield (Andrews 2005).

There is documentary evidence of the importation of brick from the Low Countries during the thirteenth and fourteenth centuries for the construction of high status buildings. It is not until the early fourteenth century (Brooks 1939; Sherlock 1998; Smith 1985), however, that commercial activity in brick manufacture emerges in Hull (Yorkshire) and Wisbech (Cambridgeshire). During the fifteenth and sixteenth centuries there was a substantial growth in the use of brick, stimulated by an extensive programme of palaces and mansions initiated by Henry V. The predominant type of brick produced during this period in eastern England, where there was a lack of good quality building stone, is the 'Tudor' which was formed on a Flemish module (230-35 by 110 by 50-60 mm) and is usually of red/orange colour. The Tudors are more uniform in size and hence more difficult to date precisely on the basis of their typology.

Luminescence dating of English buildings with independent dating evidence

Recent advances in experimental technique, notably the introduction of more sensitive procedures based on the measurement of optically stimulated luminescence (OSL), have improved the measurement precision that can be obtained routinely. We aimed to exploit this advantage in dating brick from English buildings. As a first stage of the study, an evaluation of the potential of OSL to establish a benchmark for the use of the method to date the manufacture of ceramic building materials was undertaken using samples taken from a group of buildings with independent dating control. Four buildings in Lincolnshire served as dating controls - these were Tattershall Castle, Tattershall, Ayscoughfee Hall, Spalding; St Mary's Guildhall, Boston and Doddington Hall, Doddington, ranging in date of construction from the late fourteenth century to the late sixteenth century (Table 1; Fig. 1). The dating evidence for these buildings (Bailiff 2007) is based on documentary sources and architectural stylistic assessment, together with detailed structural analysis in the case of St Mary's Guildhall (Clark et al., 2003) and Ayscoughfee Hall (Clark and Mellor 2005). Brick samples were obtained from walls associated with the primary construction phase of each building, for which a date range could be assigned within relatively tight constraints (Table 1). At Tattershall Castle (lab. ref. 318), two brick samples were obtained from the interior walls (date range: 1445-1450) of the north-east and north-west towers at the ground floor and the basement levels respectively; at the late Elizabethan Doddington Hall (lab. ref. 317) built between 1593 and 1600, two bricks were obtained from an internal foundation wall in the south wing directly below the ground floor in a cellar; at St Mary's Guildhall (Lab. ref. 310) a

brick was sampled from the north elevation of an exterior wall that is associated with the original phase of construction of the building (date range: 1390-1395); at Ayscoughfee Hall (Lab. ref. 319), a brick in the upper part of an internal gable wall associated with the original structure was sampled (date range: 1450-1455). The luminescence dates obtained for these samples (Table 1) are in excellent agreement with the assigned dates and the mean difference between the central values of luminescence and the assigned ages was 5±10 years (s.d., n= 6); full details of these are published in Bailiff (2007).
The testing of known-age material in this manner is of methodological value because of the inherent assumptions made when calculating dates using experimentally determined data, the context of which is discussed in the following section.

METHODOLOGY

A brief overview of salient technical issues relevant to the application of the luminescence method (Aitken 1998) to brick dating is given before discussing the selection of buildings and samples. The luminescence age is calculated by determining experimentally two quantities, the palaeodose, P, and the dose rate, $\dot{D}_{tot}$, using the simplified age equation:

$$\text{Luminescence Age} = \frac{\text{Palaeodose}}{\text{Dose rate}} = \frac{P}{\dot{D}_{tot}} \qquad \pm\sigma_A;\ \pm\sigma_B \text{ (years)}$$

The two error terms, σ_A and σ_B, are calculated (in this work) using a procedure derived from a specification given by Aitken (1985) and are based on an assessment of uncertainty associated with the quantities used to calculate the age. The term, σ_A, is used when comparing dates produced by the same laboratory and the term σ_B, also referred to as the overall error, is used when comparing the luminescence dates with dates obtained using other methods. Unless stated otherwise, the uncertainties are given at the 68% level of confidence ($\pm 1\sigma$).

For the samples discussed in this paper the paleodose, P, was determined using the quartz inclusion technique, following an experimental methodology developed for dating brick (Bailiff 2007) that is based on the measurement of optically stimulated luminescence (OSL) with 'coarse' grains of quartz (90-150 μm diameter) extracted from the ceramic matrix. The average dose rate since manufacture was determined by making contemporary measurements of the components of the dose rate arising from radionuclides located within the sampled brick, the wall and the local environment, and also from cosmic rays. In deriving the average value it was assumed that the sampled brick and its environment had not changed substantially, and that the gap between manufacture and use corresponds to a small fraction of the age of the brick. The dose rate to coarse grains of quartz typically comprises a 60% contribution from radionuclide sources located within the sampled brick (β radiation), about 35% from sources in the wall and materials within the local environment (γ radiation), and about 5% from cosmic radiation. There may also be a small contribution (<5%) from radionuclide impurities present within the quartz grains. If brick is sampled from a secondary rather than a primary context (i.e., reused), it is necessary to adjust the dose rate to account for potential differences between the nature and composition of the environment external to the sampled brick in its primary and secondary contexts. This can be achieved using a procedure (Bailiff 2007) that adjusts the average dose rate to take account of periods of primary and secondary use (discussed in the notes to Table 3).

Sampling procedures

A diamond-tipped core drill (either 50 mm or 38 mm dia.) was used to obtain solid cores that extended from the front face to the rear of the brick. The diamond core drill leaves a precisely cut hole which can be filled with lime mortar, finishing either using mortar coloured with brick dust or a cap comprising the surface section cut from the core. An alternative procedure to coring is the extraction of a whole brick by removal of the surrounding mortar. This allows a section to be cut from the rear of the brick and subsequent replacement can be achieved without damaging the front face of the brick, although it has the disadvantage of being a considerably lengthier extraction process. The extraction of solid cores allows quartz grains to be extracted in the laboratory from the inner part of the brick (~8-10 cm from the surface), which has advantages in terms of reducing the uncertainty in the dose rate. By avoiding the sub-surface region of brick, contributions to the dose rate from radionuclide sources located beyond the immediate vicinity of the sampled core such as plaster layers or adjacent walls are reduced due to

shielding by the brick material located between the volume sampled (yielding the quartz grains) and the external surface. The application of plaster to the outer surface of rubble walls is known to have been practised in the construction of early medieval buildings, but this generally no longer survives. In the case of an external wall, such plaster would have provided additional shielding from radiation emitted by sources in the ground. Fortunately, lime-based plaster and mortar usually contain very low concentrations of radionuclides and the effect on the dose rate due to differences in shielding is expected to be only slight. This effect has been assumed to be negligible where mortar was present in the buildings discussed below.

Medieval bricks generally have fabrics that are sufficiently coarse to yield an adequate quantity of coarse quartz grains, and the finer fabrics of the Roman bricks tested in this study also contained sufficient crystalline material. In two of the buildings sampled (e.g., Colchester and Lower Halstow, discussed below), samples taken from the same wall were found to exhibit markedly different levels of OSL, one being bright and the other too dim to measure. The luminescence sensitivity of the quartz (to dose) is related to both its geological origin and thermal history, and the firing conditions can cause a strong reduction in sensitivity, but this cannot be detected by external inspection of the brick.

In addition to extracting a brick core, a 'dosemeter' capsule (comprising a silica tube approx 15 mm dia. x 25 mm long) containing specially prepared crystals is inserted into the wall at the time of sampling. The crystals contained in these capsules measure directly the dose rate due to γ radiation emitted by radionuclides in the wall and in the immediate environment of the sampled location, and also cosmic radiation. The capsule is placed in a hole (~1 cm dia.) drilled into a mortar layer near to the core location to a depth that is sufficient to place it within the rear half of the brick (usually ca 10 cm). The period of measurement is normally at least several months (shorter periods are feasible), after which the capsule is retrieved for measurement and evaluation by the laboratory. In situ measurements can also be made with instruments to determine the intensity of the gamma radiation in the drilled cavity, although this generally gives rise to a higher uncertainty in dose rate compared with that obtained using a dosemeter.

THE BUILDINGS

The buildings studied are divided into three groups: a) sixth- to eleventh- century medieval ecclesiastical buildings where brick, judged to be reused Roman *spolia*, was used systematically in flint rubble walls (e.g., to form quoins), b) twelfth- to thirteenth- century ecclesiastical buildings where great bricks were used similarly in flint rubble walls and c) fifteenth- and sixteenth- century secular and ecclesiastical buildings built with 'Tudor' brick. The locations of the buildings are shown in Fig. 1.

Sixth- to eleventh- century medieval ecclesiastical buildings

The first group comprises five early medieval churches (Fig. 1), three in Kent (St Martin's, Canterbury; St Margaret's, Lower Halstow and St Margaret's, Darenth), one in Essex (Holy Trinity, Colchester) and the fifth in Northamptonshire (All Saints, Brixworth). All are considered to have been established within the period A.D. 600-900. The external structural walls of the buildings in Kent and Essex are likely to have been originally plastered with a lime mortar (Taylor and Taylor 1965) and the much larger church of Brixworth was built mainly in stone. CBMs were used in the form of tiles or bricks deployed in various contexts, including quoins and door jambs, and at Brixworth they were also used as structural components.

St Martin's Church, Canterbury

The church is located on a low-lying hill within the eastern part of Canterbury and positioned outside the Roman walls on a site where there is evidence for the presence of an earlier Roman building (Jenkins 1965). A church dedicated to St Martin of Tours and located east of the Cathedral is reported by Bede to have been established during the later Roman period and later used by Queen Bertha (c. A.D. 580), although a specific association with the standing church is uncertain (Taylor and Taylor 1965, 143-145; Tatton-Brown 1980, 12-18; Bell 2005, 124). Stylistically, the nave and the chancel are firmly attributed to the Anglo Saxon period. The walls are constructed of flint rubble with courses of ceramic dressing accepted to be of Roman origin and the western section of the chancel may incorporate part of an earlier Roman building (Tatton-Brown 1980). The latter is thought to date to the fourth century by comparison to Roman walls incorporated in the ruined chapel at Stone-by-Faversham (Taylor and Taylor 1965, 575). The south wall of the present chancel is considered to be the original fabric of the early medieval church. Two locations were sampled, both within brick door jambs of blocked doorways.

The first (Table 2, 354-1) is a square-headed doorway (lintel of reused Roman stonework) within the original south chancel wall and the second (342-2), to the east of 354-1, is a round headed doorway in the later nave wall which, although a later insertion, is stylistically of Anglo Saxon construction and considered to be of similar age to the present nave (Taylor and Taylor 1965, 143-145). Hence, according to current interpretation of the phasing of the chancel and nave, it is possible that the jambs of the square-headed doorway were already installed within a surviving section of an earlier Roman wall, whereas the jambs of the round-headed doorway are thought to be associated with the construction of the Anglo Saxon nave.

All Saints Church, Brixworth, Northampton

The church is a monument of key importance in the establishment of Christianity in England. Its construction during the late eighth century has been proposed on the basis of architectural analysis of the standing building and documentary evidence for the foundation of a monastery, presumed to be at Brixworth (Parsons et al. in preparation). The church comprises an apsidal chancel, surrounded by a below-ground ambulatory or ring crypt, a choir, nave, south-east chapel and west tower with a spire and a stair turret attached to its west face. Bricks are used extensively as dressings in the masonry and the characteristics of their fabric suggest Roman manufacture, although the motivation of early medieval builders for using such large quantity of brick in an area that lacked a large source of Roman brick locally still remains enigmatic (Everson and Parsons1979). Studies of the stone work indicate a mixture of locally sourced material and *spolia* from various sources, some which are Roman (Sutherland 1990). Excavations in 1972 were undertaken to recover evidence of the monastic precinct and, as part of that work (Everson 1977), samples of brick were taken in 1975 at eight locations in the main fabric of the church by Oxford University for TL dating analysis. Although further TL work was not undertaken on the samples by Oxford, five of the original ceramic samples (Table 2), including three that had been tested (Table 2, nos 8, 9 and 15) and two that had not yielded a result (nos 2 and 3), were later acquired by the Durham Laboratory for further investigation.

St Margaret's Church, Lower Halstow

Although much of the standing church is of the thirteenth century, this church has a square chancel that has been assigned stylistically to the Anglo-Saxon period (Olive 1918; Taylor and Taylor 1965, 281), a Norman aisled nave, a thirteenth-century tower constructed on the western part of the south aisle and a modern porch and north chapel. The church was built on an embankment of the river Medway estuary in north Kent, in an area where there is evidence of widespread use of spolia from Roman settlements (Bell 2005, 104, 226). The existence of the church is noted in the *Domesday Monachorum*, ca 1100, and it is presumed that the original church was constructed during the tenth or eleventh century. The fabric of the walls is composed mainly of flint and blocks of clunch. Various ceramics, including *imbrices* and *tegulae*, can be found sporadically in the wall masonry, particularly in the south wall of the chancel. They are used more systematically to form an *opus spicatum* in the lower parts of the wall, and are stacked in the western section of the chancel wall. Most of the these ceramics were used in a fragmentary state and some display traces of *opus signinum* still adhering to their faces, indicating reuse of Roman material in the construction of the early medieval church. Core samples were obtained from two bricks in the southern wall of the chancel (Table 2), one (344-1) being a harder and finer matrix from the stack and the other (344-2) from the adjacent *opus spicatum* having a coarser matrix.

St Margaret's Church, Darenth

The church was built on a hillside within the parish of Darenth which is located in north western Kent and several km from Watling Street. There is evidence within Darenth of Roman settlement in the form of a palatial villa (located 500 m south of the church, built between the second and fourth centuries and abandoned during the fifth or sixth centuries), early Saxon structures and the later development of a village (c. during the seventh or eighth centuries) that ultimately formed the basis of the present town (Philip 1984). The construction of the original church with flint rubble walls is attributed to Anglo-Saxon builders (Taylor and Taylor 1965, 191). A charter of Christchurch of Canterbury dated AD 940 refers to a manor in Darenth, suggesting the existence of a church, and the building is also mentioned in the *Domesday Boo*k. Although it is not clear whether the present church was built before the Conquest, the construction has been assigned on stylistic grounds to between the late tenth to early eleventh centuries (Elliston-Erwood 1912). The church has a narrow nave (11x5 m) which probably constitutes the standing part of the original church, flanked with later medieval additions (Elliston-Erwood 1912; Taylor & Taylor 1965). Ceramic is used sporadically in the north and west walls of the nave and systematically in the north-west, north-east and south-east quoins, and is also used as a form of *opus spicatum* at various locations. One core sample was taken from the north-east quoin of the nave (Table 2).

Holy Trinity Church, Colchester
The church is located in the heart of Colchester (Essex) which developed substantially as a Roman settlement during the second and third centuries AD. There is little surviving archaeological evidence for occupation of the settlement in the early Saxon period and, apart from some possible references in ninth/tenth century Anglo-Saxon sources, the first explicit records appear in the late twelfth century (Cooper and Erlington 1994, 309-311). The discovery of walls from an earlier church under the floor of the current nave and the architectural features of the earliest phase (Rodwell and Rodwell 1977, 32; Taylor and Taylor 1965, 162) suggest that the building of the original church was in the ninth or the tenth century. The fabric of the walls of the western square tower (earliest surviving phase) contains flint and *septaria* rubble, and the walls contain horizontal rows of bricks (including string courses marking different stages of the tower). Bricks were also used for the quoins and all the apertures in the tower, and to form the stepped square-sectioned imposts. Although it has been suggested that the ceramics could be of Anglo-Saxon origin (Minter et al. 2006), the presence variously of *opus signinum*, traces of digitation on the brick surfaces and fragmentation indicates reuse of Roman materials. Cores from two bricks forming the jambs of the internal western doorway that formed part of the original church were sampled (Table 2).

Twelfth- thirteenth century ecclesiastical buildings with great bricks
The second group comprises three churches built between the eleventh and twelfth centuries: St Martin's, Chipping Ongar, St Andrew's, Boreham, Holy Trinity Church, Bradwell-juxta-Coggeshall and the infirmary of Coggeshall Abbey. All the buildings are located in Essex (Fig. 1). As for the buildings in the first group, the main external structural walls of these buildings were built of flint and stone rubble with flint dressing, and CBMs were used as quoins, door jambs, voussoirs and as structural elements of brick walls. In the case of Bradwell-juxta-Coggeshall there is surviving evidence of the use of lime mortar plaster on the external walls (Rodwell 1998, 59).

St Martin's Church, Chipping Ongar
Chipping Ongar, located 20 km east of Chelmsford, is at the crossing of several ancient roads, including one leading to London. There is evidence of settlement since the Roman period (Powell 1956, 159) and in the Anglo-Saxon period it developed as a market town, becoming the administrative centre of the Saxon Hundred. The earliest documentary reference to the manor of Ongar occurs in a will (AD 1043-5; Whitelock 1930, 82, 84); the manor subsequently passed to a priest Ingelric, and thence from AD 1086 to the Count of Boulogne. The existence of an associated church is implied by the mention of a manor, and it is presumed that a church has existed in Chipping Ongar at least since the eleventh century. However, there are currently no known surviving historic sources related to the origins of the church building. The church has a long and narrow nave (18x7 m), with a south aisle and other elements added in the ninth century. The fabric of the walls is rubble, faced with well sorted flint and horizontal rows of bricks. Brick is also used as dressings to form the quoins and the original south doorway, a feature that was subsequently blocked. Earlier windows are visible in the eastern part of the north and south walls of the chancel, and also in the north wall of the nave, which also contains a doorway blocked in 1884 (Powell 1956), all dated stylistically to the eleventh century. The quality of the masonry suggests a Norman origin for the church and stylistically the church has been judged to be contemporary with Bradwell-juxta-Coggeshall (Rodwell 1998, 105). Although part of the surviving roof structure is thought to include structural elements that formed part of the original church (Hewett 1982, 3), it is not clear whether the timber elements are potentially suitable for tree-ring dating.

Four bricks were sampled from three external locations of the church: the arch of the north nave doorway (363-1), a brick in the junction between the south wall of the chancel and the east face of the original south nave (363-2) and in the south-east quoin of the chancel (363-3). The fabric of the bricks has been attributed to Roman manufacture and if this is the case the finding of Roman remains in the graveyard of the parish (Muilman 1770, 316-7; Gough 1789, 51; Wright 1836, 330) indicates a nearby source of potential material. Although there are mixed opinions regarding the assessment of the brick typology, (Rodwell, 1998, 105 considered them to be medieval great bricks while Potter, 2001 argues that they are Roman), they are judged to be not directly comparable to the Coggeshall type great bricks.

Holy Trinity Church, Bradwell juxta Coggeshall
Holy Trinity is a small Norman church built on a simple rectangular plan with mixed rubble walls. Apart from later minor additions including the addition of a timber belfry, a porch and the insertion of several

new windows during the late Medieval period, the fabric is remarkable in having survived largely unaltered by later work. In a detailed assessment of the church fabric by Rodwell (1998, 59), the building is considered to be an exemplar of Norman construction technique, with no indication of the presence of an earlier structure. Evidence of the reuse of some Roman building materials was found within the rubble walls, but the red bricks used as dressing of the quoins, doors and windows were judged to be a distinctive medieval type and fabric, manufactured for the construction of the church. Typologically they were considered to be a Coggeshall type brick. On the basis of the style of fabrication and architectural form, the construction is dated to the second quarter of the twelfth century. However the similarity of some the features, including the narrow doorways and windows, with those found in other eleventh-century Essex churches is also acknowledged. The sampled brick was located in one of the jambs of the doorway within the south elevation of the nave.

St Andrew's Church, Boreham
The church is unusual in having a central tower with the chancel to the east and the nave to the west. Remnants of an earlier structure, stylistically Anglo-Saxon and believed to date to c. AD 950-1100 (Taylor and Taylor 1965, 79), have been identified in the church fabric comprising a chancel and an aisleless nave that no longer exist, with the exception of the eastern ceramic tile quoins. It is suggested that the walls of the chancel were used to form the lower part of the massive Norman tower (Bettley and Pevsner 2007, 153; Taylor and Taylor 1965, 80). The ceramic building materials are generally of Roman type (Rodwell 1976; Smith 1988, 139-140; RCHME 1921, 22), and there is archaeological evidence of Roman settlement in the area that would have provided a source of reused building materials (Lavender 1993). However, Ryan (1996, 26) has also noted the use of Coggeshall type brick in the second stage of the central tower and the eastern quoins of the original Saxon nave are also Coggeshall type brick above a height of ca 1.6 m (those below are of Roman type). One sample was obtained from interior exposed brick quoins of the northern respond of the arch between the present chancel and the tower, believed to have been of Norman construction (c. late eleventh century). Although the presence of wall plaster prevents a full assessment of the brick dimensions, the fabric is similar to the Coggeshall type and the length of core obtained (150 mm) consistent with the width of the rectilinear type.

Coggeshall Abbey
Coggeshall Abbey was established in ca 1140 by the Order of Savigny but became a Cistercian abbey in 1148 (Fowler 1907, 125). The use of large and very precisely made bricks at Coggeshall has given rise to the term Coggeshall type brick, a wide range of moulded forms of which were used in the construction of the abbey. The chronology of construction of the buildings in the abbey complex is not precisely known. The dedication of the high altar in 1167, as recorded by Ralph de Coggeshall (Fowler 1907, 125), suggests that the presbytery of the main church could had been constructed during the 1160s. A few of the original buildings remain, but most were demolished or incorporated within a manorial complex that was established during the sixteenth century (Gardener 1955, 30). Structural elements of an infirmary can be found within the manor house, including a brick column with a scalloped capital and springing for a lancet arch that remains intact within the wall on the next floor. A brick within the column was sampled and hence presumed to have a mid-twelfth century date as a terminus post quem.

Fifteenth- and sixteenth- century secular and ecclesiastical buildings

The late medieval buildings selected are of secular (Maldon Moot Hall, Nether Hall, Layer Marney Towers and Eastbury Manor) and ecclesiastical (Woodham and Earls Colne) origin. Multiple samples were obtained in the cases of Nether Hall (3) and Eastbury Manor (7) to examine the degree of consistency obtained in the luminescence dates in comparison with available independent dating evidence. However, the confidence with which dates for the construction of later medieval buildings in Essex can be derived from an assessment of stylistic features, documentary evidence and other relevant data varies considerably (Gurling 2009).

Maldon Moot Hall
The Moot Hall is a three storey brick tower house complex that was built in the fifteenth century (Bettley and Pevsner 2007, 581; Ryan 1996, 52) and probably formed part of a larger mansion which, with the exception of the tower, is thought to have been demolished between 1536 and 1560 (Petchey 1991). By the end of the sixteenth century only the tower, known as Darcy's Tower, remained. Demolition of adjacent buildings in 1991 provided further evidence of the existence of the manorial complex and also

that additions had been made to the Moot Hall, probably in the late fifteenth century. Various arguments have been advanced concerning when in the fifteenth century the tower was constructed; most recently Andrews (2005, 145) has argued that it occurred between the 1420s and 1430s, which would make it the earliest surviving purpose-built brick structure in Essex. Recent restoration work has uncovered distinctive features (Andrews 2007, 2-8) in the form of ruddled brickwork and trefoil headed arches with elaborately moulded corbels. The building also incorporates a newel staircase that is built entirely of brick within an octagonal turret which is rare in the fifteenth century (Smith 1976, 46-48; 1975, 137-138). These features are also found in tower houses in Lincolnshire that were built in the middle of the fifteenth century (e.g., Hussey Tower; Boston; Smith 1979, 34, 36; 1985, 48; Emery 2000, 351-352) and are thought to have been inspired by the construction of Tattershall Castle. The sample was taken from the base of the staircase, dated to the 1420s -1430s on the basis of the current assessment by Andrews (2005, 145).

Nether Hall

Nether Hall was built as a fortified moated manorial complex but is now largely a ruin and only part of the brick gatehouse survives. It is thought that it may have been built by Thomas Colt (died 1467) who was granted estates in Essex between 1462 and 1464 (Cal. Pat. Roll. 1461-1467), but without specific mention of Nether Hall (Gurling 2009, 118). Although records of the exact date of construction have not survived, the building has stylistic features that are similar to those found in fifteenth-century buildings in the county and the current assessment of the date range for its construction is c. 1447 to 1467 (Andrews 2004, 79; Ryan 1996, 59). Cores were taken from three bricks in a wall at the base of a brick newel staircase.

Earls Colne

The church was extensively restored in the nineteenth century but the fabric of the chancel and southern aisle, assigned to the first half of the fourteenth century, is original (RCHME 1922, 87). It has an imposing three stage tower that, based on stylistic assessment of the fabric, was constructed over an extended period, starting during the mid-fifteenth century. The completion of the tower is assigned to the early to mid sixteenth century, as indicated by a date plate of 1534. It is thought that on the death of the thirteenth Earl of Oxford in 1513 the tower remained unfinished and by 1525 it still remained so, with part of the tower also requiring rebuilding (Gurling 2009, Ch. 3). The walls of the lowest stage of the tower, dated stylistically to ca 1450, are built of rubble and contain Roman tile; the second stage east wall, constructed in brick and containing lights with fifteenth-century trefoiled heads in the east and west walls, cannot be tied down more specifically than to 1450-1525. One brick sample was obtained from the east elevation of the second stage of the tower and is consequently thought to date to the same period.

Layer Marney Towers

Layer Marney Towers is a high status building of the early sixteenth century known for its early English Renaissance terracotta decoration (Campbell and Pryce 2003, 141; RCHME 1922, 158). Within the complex of buildings, a tall gatehouse built in brick with ornate decoration forms a dominant visual focus. Although the complex has not been the subject of a detailed architectural assessment, there is surviving documentary evidence associated with the Marney family who are thought to have begun building what became an unfinished manorial complex. The principal buildings comprise the gatehouse with attached east and west wings, a long gallery range and a church, all built in brick. There is also a timber barn that has been dated to the mid-fifteenth century, although some of the timbers were felled in the thirteenth century and hence are reused. A connection by marriage was established which linked the Marney family with the owner of Heron Hall, near East Horndon in Essex, that was built in brick and thought to have been constructed during the first half of the fifteenth century (Ryan 1996, 51), and this may have influenced the construction of the original manor complex at Layer Marney. It is likely that a series of buildings comprising an earlier manorial complex were demolished or altered to make way for the construction of a grand courtyard house. The new building work was started by Henry Marney in the early sixteenth century and continued by his son John, but terminated at some stage, probably on the death of the latter in 1525. The current estimate for the construction date of the tower is 1510-1525, and the use of terracotta in the tower suggests the latter part of this range since the material was being used in various parts of England in ca 1520 (Wight 1972, 180). A brick sample was taken from an interior wall of the first stage of the eastern tower of the central gatehouse.

Woodham Walter

The church at Woodham Walter is a rare example of a mid-sixteenth-century ecclesiastical building in Essex constructed in brick. Documentary evidence indicates that an earlier church, of the late twelfth/early thirteenth century and located 500 m SE of the present church, was demolished and that a licence was granted to build a new church (*Cal. Pat. R., 1560-1563*). The Tudor church is dated to 1562-1564 on the basis of the licence and date plate (1563). It is thought that the walls have a rubble core (Ryan pers. comm.) and the brick bonding pattern used is made distinctive by the predominant use of stretcher faces, possibly to reduce the quantity of brick required. An examination of the fabric and architectural features indicates that reused materials of the fourteenth and fifteenth centuries are incorporated in the building, and timbers within the belfry have been dated to the late fourteenth century (Tyers et al. 1997, 142). There is a date plate marking the construction of the church in 1563 and the consecration of the church in 1564 is documented (Morant 1768, vol. 1, 340). One sample was taken at the second stage from the interior wall of the western elevation of the belfry that was incorporated in the rebuilt church of ca 1563.

Eastbury Manor

Eastbury Manor is an Elizabethan brick mansion built on an H plan. It is thought that an earlier building owned by Barking Abbey until the Dissolution in 1539 may have been constructed on the site or close to the present building. Records indicate that a messuage was passed to Nicholas Stoddard before being granted to Sir William Denham in 1545 (Oxley 1966, 201). After his death in 1548 it passed through various hands until 1557 when it was bought by Clement Sysley who, shortly after 1560, started the new building work that led to the construction of the present manorial complex. A tree-ring date for the roof timbers of the spring of 1566 (Tyers 1997), combined with the architectural assessment (Cherry et al. 2005, 130; LSC 1917, 19; RCHME 1921, 9), places construction within the interval 1557 to 1566, although the presence of some earlier architectural features have been noted. A total of eight brick samples were taken, comprising a pair from each of four sampled walls, these being in the cellar (340-1,4); in the south-west corner of the first floor, the Panelled Room (340-2,5); in the north-east corner of the first floor, the Summer Parlour (340-3,6) and finally one sample in the south-east corner of the attic space (340-7).

DATING RESULTS AND DISCUSSION

The luminescence dating results are summarised in Table 2, and key technical data associated with each date calculation are given in Table 3. The assigned building dates and luminescence dates are plotted in two groups (Figs 2a and 2b), shown in chronological order according to the archaeologically assigned date range for the sampled phase. The OSL date was initially calculated assuming the brick was in a primary context, and for those cases where archaeological evidence suggested reuse, the OSL date was recalculated by adjusting the average dose rate (see notes to Table 3) to make an allowance for the potentially different environment in which the brick had been located prior to construction of the wall, the estimated date of which was derived from the archaeological assessment of the fabric. Although for the cases considered here the adjustment to the dose rate is small (average increase of 1.6%) it is important that the effect is taken into account in the dose rate assessment procedure.

Reused Roman bricks in Saxon churches

For the early medieval buildings, namely the churches of Canterbury, Brixworth, Lower Halstow, Colchestser and Darenth, the OSL dates are consistent with the archaeological assessment that the CBM are Roman *spolia*. The difference in OSL dates obtained for the two Canterbury locations (comparison using σ_A), corresponding to the door jambs of the blocked doorways in the south elevation of the chancel (345-1; 70±120) and the south elevation of the nave (345-2; 282±118) is statistically significant and indicates that recycled material from another structure or a separate source of CBM was used in the later phase. If the brick at location 345-1 were reused during the fourth century, and the context consequently secondary, the OSL date is slightly earlier but not significantly different. Hence, although the OSL result cannot resolve the question of whether the date of brick manufacture and the date of wall construction are contemporary, the OSL date for sample 345-1 using either mode of dose rate calculation is consistent with the suggestion that the chancel south doorway is contained within a reused section of Roman wall.

All of the five dates obtained for Brixworth samples clearly indicate Roman origin, and form a consistent group using Ward and Wilson's (1978) test statistic, T , with a pooled mean date of 105±110 (T=4.4;

$\chi^2_{4,0.05}$ =9.49). Although the clustering of dates for samples Bx 3, 8, 9 and 15 (range 31-74) suggest that sample Bx 2 may have been taken from a later building, the precision in the individual dates (σ_A) is not sufficient to demonstrate a statistically significant difference in age. Although these results were obtained from a comparatively small number of bricks, the samples were selected in 1975 on the basis of having a fabric judged to be of potentially medieval type. Of the TL dates produced by the Oxford Laboratory, one indicated Roman origin (no. 5; A.D. 200-600), and the other three were medieval (no. 8, AD 1400-1600; no. 9, AD 750-1050; no. 15, AD 700-1000). However, the fine grain TL technique used by Oxford (not stated explicitly in Everson 1977, but reported in Everson and Parsons 1979) is now known to be susceptible to the problem of anomalous fading associated with the presence of feldspar crystals in measurement samples which, if present, would have led to an underestimate of the age (Aitken 1985, 9). We did not attempt to reanalyse the material using the fine grain technique, but it is likely that the dates obtained for samples 8, 9 and 15 were underestimates due to this effect and should not be considered reliable. The estimated manufacturing dates for the bricks sampled from the later churches of Colchester (40±135), Darenth (257±117) and Lower Halstow (325±125), are consistent with the known Roman settlement in the relevant areas that potentially would have provided sources of building material.

Great bricks in eleventh- and twelfth- century ecclesiastical buildings

The dates obtained for the group of churches including Chipping Ongar, Bradwell juxta Coggeshall and Boreham, together with Coggeshall Abbey, provide an interesting group of results because of the significance of the bricks associated with the latter site.

The OSL date obtained for the Coggeshall Infirmary pillar brick (1144±58) is consistent with the presumed date range for the construction of the abbey. The uncertainty in the date is higher than for other bricks and this is associated with heterogeneity in the brick fabric. Since there is no independent documentary evidence for the date of construction of the abbey, this result supports the assessment by Andrews (2005, 142) that bricks were being manufactured at Coggeshall by the 1160s and provides the first independent dating test for this type of brick. Although the bricks used in Bradwell are assessed to be of Coggeshall type, the OSL date of 1038±60 obtained for the door jamb brick is significantly earlier than the date for the Infirmary brick (based on σ_A). The OSL date range just overlaps (at $2\sigma_B$) with Rodwell's (1998) assigned range of 1125-1150 for the construction of the church. However the OSL date, combined with Rodwell's assessment that the bricks were newly fabricated when used and also his identification of architectural features similar to eleventh-century churches in the same region of Essex in the church, raises the possibility that construction occurred during the early post-Conquest period. If, on the other hand, the bricks were reused, an adjustment made to the dose rate (as discussed above) would change the average dose rate only marginally and the OSL date of manufacture is not significantly altered.

In contrast, the OSL date for the brick from Boreham (896±68) is significantly earlier than the OSL dates for the other two churches. If the Norman builders had reconstructed the wall containing the sampled (reused) brick, calculations of the dose rate for different environments including a solid brick structure (the dose rate for which is expected to be higher than for a flint rubble and mortar fabric) and allowing a period of primary use of 100-200 years, changes the date only slightly, moving the central value into the early tenth century.

The OSL dates for Chipping Ongar form a consistent group when tested statistically (samples 1a, 1060±64; 1b, 1011±68; 2a, 1025±61; 3, 1005±58; T=0.5; $\chi^2_{4,0.05}$ =9.49), with a pooled mean date of AD 1025±56 (pooled mean, σ_B). The latter is consistent with the late eleventh century estimate of the date of the earliest phase of construction of the church (RCHME 1921, 52), while Rodwell (1998) places the construction in the mid-twelfth century. In these more recent assessments the bricks are considered to be neither Roman nor directly comparable to the Coggeshall type bricks, although they have the dimensions and fabric type within the range of great bricks. The possibility that the bricks were imported, arising from the association of the manor of Ongar with the Count of Boulogne in the late eleventh century, cannot be discounted but, as indicated by the results for Bradwell and Boreham, they could represent early eleventh century precursors to the Coggeshall type brick manufactured in Essex.

The results for Bradwell, Chipping Ongar and Boreham help to clarify the chronological relationships between the three churches, albeit with a small number of sampled bricks. The OSL dates confirm the contemporaneity of the rectilinear great bricks used at Chipping Ongar and the Coggeshall type bricks used at Bradwell and, significantly, place both in advance of the fabrication of the distinctive great bricks used at Coggeshall Abbey. If the bricks were of local manufacture, this finding supports Rodwell's suggestion that established brickmakers had already arrived in Essex before the construction of Coggeshall Abbey (during the second quarter of the twelfth century). Although Rodwell was not able to find evidence of the use of great bricks earlier than at Bradwell and Coggeshall Abbey, he identifies 6 churches within the local area (Barnston, Boreham, Great Baxtead, Great Leighs and Fairstead) where Coggeshall type brick appears in primary contexts and thirteen further buildings where it is present in small quantities. He refers to the identification by Ryan (1996, 26) of the use of moulded Coggeshall 'specials' to construct a twelfth-century newel stair at Fyfield church (some 33 km SW of Coggeshall, point-to-point, and close to Chipping Ongar) which he considered anomalous, although the parts of the church where the Coggeshall brick is used have been dated to the late twelfth to early thirteenth centuries and hence may be reused (Gurling, 2009). Apart from the churches with Coggeshall type brick, he also notes that there are only two known occurrences of early medieval plain 'great brick', these being in Essex (Chipping Ongar) and in neighbouring Suffolk, at Polstead church. Both churches are considered to be contemporary with Bradwell, having Norman brickwork dated to the middle of the twelfth century. The range of the four OSL dates obtained for Chipping Ongar could accommodate early Norman manufacture and, if the attribution of mid-twelfth century Norman construction of Bradwell (Rodwell 1998, 98) is firm, two possible interpretations are that the bricks: a) are of early Norman manufacture, used promptly in construction; b) were made shortly following the Conquest and either stored or reused in construction in the mid-twelfth century. However, taking either interpretation, the addition of the Boreham dating result, despite the uncertainties regarding the nature of the context sampled in that church, adds weight to the possibility of fabrication of great bricks in the tenth or eleventh centuries and merits a more detailed investigation.

Tudor bricks in late medieval buildings

The dates obtained for the three bricks from Nether Hall provide an indicative measure of the dispersion to expect when testing Tudor bricks from a wall fabricated with what is believed to be a coeval set of bricks. They form a coherent group (T=1.7; $\chi^2_{2,0.05}$= 7.8), the average OSL date for which is 1458±32 (pooled mean; σ_B; samples 3, 5 and the average of 4a and 4b). The range, Δd, corresponds to 39 years and the average date is in excellent agreement with the assigned construction date range (AD 1447 to 1467; Andrews 2004, 95). This is instructive in assessing the results for Eastbury Manor, the value of Δd for which (67 years; 1478 to 1545) is almost double that for Nether Hall. Examination of the distribution of the dates (Fig. 2b) suggests two groups comprising 'early' (340- 4, 5, 6, 7) and 'late' (340-1, 2, 3) dates. In the case of the cellar (340-1, 4), the Panelled Room (340-2, 5) and the Summer Parlour (340-3,6), the dates obtained for each of the two samples from the same wall at each location fall into each group (early vs. late). This observation, combined with finding that the attic sample produced the oldest date (340-7, 1478) and one of the cellar wall bricks produced the youngest date (340-1; 1545), indicates that the building was likely to have been constructed with a mixed stock of bricks. One possible source of some of the bricks being nearby Barking Abbey which was variously stripped for building materials following the Dissolution (Clapham 1913, 72). The pooled mean (where σ_A was used as the weighting factor) of the 'early' group of dates is 1493±16, indicating that the bricks used could have been at least 50 years old. Although the individual dates within the 'late' group do not exclude the manufacture of the bricks being contemporary with construction of the house in ca 1566 (on the basis of the tree-ring date for the roof timbers), the pooled mean for the 'late' group (1535±18) raises the question as to whether brick from another source was also used. This is supported by the presence of vitrified bricks in the cellar wall that originally may have been used for diaper work, a common decorative feature in pre-Reformation brick structures (Smith 1985, 11).

Although the single determinations obtained for the remaining buildings, Maldon Moot Hall, Earls Colne, Layer Marney and Woodham Walter, do not provide the scope for analysing distributions of dates, individually they have produced results that suggest further determinations to improve the dating precision would be worthwhile. Most significant of these is the OSL date for Maldon Moot Hall (1393±36) which confirms the tower to be the earliest standing brick structure in Essex and may be even earlier than that suggested by Andrews (2008; 1420s-1430s). The OSL date (1447±35) for the brick from Layer Marney Towers is older than the assigned age range (1510-1525). From an analysis of the structure there is evidence that materials from an earlier manorial complex were incorporated in the fabric of some of the standing buildings (Gurling 2009, 249-250). It is likely that demolition work

preceded construction of the gatehouse and wings, and the bricks recovered could have been reused when building the massive gatehouse. In terms of the brick typology it is plausible that the original bricks date to the first half of the fifteenth century. The OSL dates for the bricks from the churches of Woodham Walter (1505±29) and Earls Colne (1407±33), while just overlapping (2σ) with the assigned date ranges for their construction (1562-1564 and 1450-1525 respectively), suggest the possibility of reuse of brick in both cases. Although reused architectural features are evident in Woodham Walter, no standing elements of the structure of the earlier church have survived. However, the earlier church could have provided a source of brick (e.g., brick encasement to restore decaying rubble walls) that resulted from the development of Woodham Walter Hall, built in Tudor brick by Robert Radcliffe, the first Earl of Sussex, in the early sixteenth century (Ryan 1996, 85). In the case of Earls Colne, Earls Colne Priory, which had been destroyed by 1631, is a potential source of reused brick. There is both documentary (Cooper 2001, 97; Ryan 1999, 93) and archaeological evidence (Fairweather 1937, 282) to suggest that bricks were being manufactured close to the priory at the beginning of the fifteenth century. In terms of establishing the early use of 'Tudor' brick in Essex during this period, the dates for both Maldon Moot Hall and Earls Colne church are comparatively early for the use of brick in Essex and buildings such as Earls Colne Priory could have served as a source of brick in the construction of other later buildings. This raises the possibility of finding as yet undetected brick of the early fifteenth century within a wider area in Essex and may have important implications for the brick typologies that have been established for brick in Essex (Andrews 2005).

OVERALL EVALUATION OF THE DATING RESULTS

The OSL dates for bricks from Anglo-Saxon churches (Canterbury, Colchester, Darenth and Lower Halstow) have, as expected, corroborated past and current observations that Anglo-Saxon ecclesiastical building traditions included the decorative and functional reuse of ceramic building materials confirmed to be of Roman origin, obtaining estimated (OSL) dates of manufacture that are consistent with known periods of Roman settlement within the local areas. Although the original objective in testing brick from Anglo Saxon contexts was to obtain age estimates for manufacture of the brick with sufficient precision to indicate whether the material was reused or contemporary with construction (i.e. medieval), the dating has also thrown up a series of additional anomalies that merit more detailed investigation. While some have argued that the recycling of Roman building material and stone was a profoundly ideologically driven choice (Bell 2005; Eaton 2000), made to reflect and resurrect the greatness of the lost Roman past and to align in visual material terms with a Continental and Roman new Christian identity, recycling may have been less specific, drawing material from a range of different structures in the vicinity of buildings. At Canterbury, for example, St. Martin's church was constructed and developed on the site of a Roman building, supported by the date obtained for a brick sampled from the earliest phase (345-1), and the OSL date for the later phase (345-2) indicates that CBM was drawn from another location or source. This points to a less selective and specific approach to reusing Roman building material than previously suspected – more functional than 'ideological'. Most significantly in the case of the Brixworth church, confirmation of Roman manufacture clarifies a long held debate regarding the possibility of medieval manufacture, as suggested by the original results of the Oxford tests, and this finding is consistent with the current interpretation of the Roman origin of the stonework. Significantly, the pooled mean date (AD 105±110) for Brixworth points to a more selective recycling of Roman building material quarried from a single structure compared with Canterbury where the dates indicate the reuse of both of *in situ* and quarried material. The results of elemental analysis of the bricks by x-ray fluorescence eliminated local Roman villas as a possible source, but was not able to pinpoint the primary source. On the basis of the stone analysis the brick is assumed to have been obtained from Leicester and its environs. The dating results suggest more specific quarrying from a source that may have been a single structure. A more detailed insight into the selection and quarrying of Roman structures to provide building material for early medieval churches requires a combined approach of dating and a method of ceramic fabric characterisation that allows the recycled CBM with its source to be conjoined. Such an approach would have the potential to resolve different choices/approaches in sourcing CBM for decorative features and structural elements, from which a spatial linking of churches to quarries would provide the opportunity to examine the patterns of ownership and Royal patronage that may lie behind the selection of CBM sources and quarries. In the long-term, the dating of CBM in Anglo-Saxon buildings, through more intensive regional and cross regional projects, may offer a means of investigating reuse of Roman material from a range of deeper and more complex perspectives, such as discerning the patterns of elite and ecclesiastical consumption explored from spatial and chronological perspectives.

Although the use of CBM in church architecture in the late Anglo-Saxon period may have been influenced by Carolingian architectural fashions, the absence of material dated to this period provides

further evidence that Carolingian CBM was not being transported and used in England, and that the technology was absent until much later, probably not until the tenth/early eleventh century on the basis of the dates for Boreham, Bradwell and Chipping Ongar. Within this milieu CBM was selected and used both in response to Continental fashions and ideological ideas, introduced to England through the advent of Christianity and through the close development of contact between S.E. England and the Continental mainland. The OSL dates for samples of great bricks from Boreham, Bradwell and Chipping Ongar, when compared with that for brick from Coggeshall Abbey, highlight the need to make a closer examination of the dating of churches in Essex built between the tenth and twelfth centuries to obtain a better understanding of when and how English brick manufacture was resumed. Although, on the basis of the dating results obtained for Chipping Ongar and Bradwell, it is not possible to show conclusively whether the bricks were manufactured post- or pre- Conquest, they provide a clear indication that manufacture occurred during the early post-Conquest period, or earlier. If, on the other hand, the construction of Bradwell and Chipping Ongar are incontrovertibly of the first half of the twelfth century, the bricks would appear to be reused. Following either interpretation, the OSL dating results provide evidence that brick manufacture substantially predates the construction of Coggeshall Abbey in the mid-twelfth century.

The dating of 'Tudor' bricks from the buildings selected produced some results that were initially surprising, in particular the indication of the use of recycled bricks at Eastbury Manor. There are relatively few documented references to the reuse of brick during the fifteenth and sixteenth centuries. These include repairs of, and alterations to, the medieval walls of Great Yarmouth (Potter 2008), repairs to Tattershall Castle with bricks quarried from the nearby Tower on the Moor and also demolished houses (Simpson 1960, 78 and 50). Fulbroke Castle, Warwickshire, built in the early fourteenth century and considered to be the earliest structural brick building in the region (Emery 2000, 380) was quarried in the 1530s by Sir William Compton for the construction of his brick mansion, Compton Wynyates (Salzman 1967, 60), the political significance of its past ownership being a probable factor in its despoilation. Other high status buildings are likely to have suffered similar fates during this period, including monastic sites abandoned during the Dissolution (Morris 2003, 237-239; Colvin 1999, 52-66). However, the Eastbury results suggest that the practice of recycling building materials may have equally applied to vernacular buildings, where material became available, and perhaps more widely than previously assumed.

Whereas buildings with Tudor brick had been sampled assuming that walls of a given phase were constructed with a coeval stock of bricks, the sampling of multiple bricks may be necessary in future to check for the presence of reused brick. Over and above this issue, the level of dispersion in OSL dates that can be obtained routinely for coeval brick also requires further investigation by multiple sampling of independently dated structures built using a single source of brick, as applied at Nether Hall . Since the dating of medieval buildings of this period is usually based on fabric and stylistic factors, and also partly draws on an assessment of brick typology, it would be appropriate to examine whether the typologies in use for 'Tudor' brick have been affected by the presence of recycled bricks of significantly different age.

NEW DEVELOPMENTS

Luminescence dating, as applied here, provides part of the information of interest when examining for the reuse of CBM, the other aspect being the date of construction. The thermal resetting of the luminescence chronometer mechanism necessarily determines the date of last heating and in the absence of evidence of secondary burning this is presumed to correspond to the date of manufacture (as also applies to the recently proposed method of rehydroxylation dating; Wilson et al. 2009). However, the OSL chronometer has the capability to be optically reset (Aitken 1998) and this opens up the possibility of dating the emplacement of bricks. The experimental approach presents a number of technical challenges (Veillevigne 2004), one being the requirement that luminescence grains located within the surface of a brick were sufficiently exposed to sunlight before use in construction and subsequently covered by layer of mortar to maintain dark conditions until tested in the laboratory. Nevertheless, its development to date the use in construction has the prospect of providing an important additional tool in building studies, and this approach can be extended to stone masonry (Vafiadou et al. 2007).

CONCLUSION

This paper offers a two-fold conclusion: it has confirmed the value of luminescence dating of CBM as way of refining structural chronologies in English Medieval building and, in broader general and social terms, the combined study has demonstrated that the sustainable approaches to other technologies

already proven in early to late Medieval England, in particular those employing timber, stone and iron, were equally applicable to CBM, including the recycling of these materials. The dating results further build on the promising outcome of the dating control tests performed with the buildings in Lincolnshire, extending the chronological range of buildings and contexts tested. If, in the case of the reused Roman CBM, a combined approach of dating manufacture and fabric characterisation can be developed with sufficient temporal and spatial resolution, there is the exciting prospect of developing a new tool for investigating the reuse of Roman material in early medieval buildings. Although the confirmation of Roman manufacture of the CBM in the Anglo Saxon churches tested suggests that reuse of Roman material persisted until the tenth century, the availability of brick manufacturing knowledge in NW France during the late Carolingian period, as indicated by the parallel dating studies in NW France, raises interesting questions concerning the choices that would have been available when sourcing CBM for use in building during the tenth and early eleventh centuries. The confirmation obtained from the three Essex churches of brick manufacture in the eleventh century, with the possibility of earlier activity in the case of Boreham, suggests that further investigation of buildings in this region of E England would be fruitful and likely to reveal wider evidence of early brick making given the identification of other buildings in Essex and Suffolk with early great bricks. Finally, the outcome of testing the Tudor bricks for Eastbury Manor highlight a need, common to testing CBM used in buildings of any age, to be able to establish both the date of manufacture and emplacement. The development of OSL for dating the latter is being investigated and would provide an important addition to the dating tools available for the interpretation of the history of buildings, particularly in the case of the early medieval structures.

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Table 1.

Building	Lab. ref.	Location	Assigned construction date range A.D.	Luminescence Date A.D. ($\pm\sigma_A$; $\pm\sigma_B$)
St Mary's Guildhall, Boston	310	1. N elevation	1390-1395	1388 ±16; ±37
Doddington Hall, Doddington	317	1a. Foundation wall, S wing 1b. "	1593-1600	1586 ±10; ±24 1576 ±14; ±27
Tattershall Castle,Tattershall	318	1. NE Tower, Ground Floor 2. NW Tower, Basement	1445-1450	1455 ±14; ±33 1453 ±15; ±34
Ayscoughfee Hall, Spalding	319	1. Loft, gable wall	1450-1455	1447 ±13; ±32

Table 2.

Building	Lab. ref.	Sample No. and Location	Assigned construction date range A.D.	Luminescence Date A.D. ($\pm\sigma_A$; $\pm\sigma_B$)
St Martin's Church, Canterbury	345	1. Chancel S elev, door jamb	C4th	70 ±55; ±120
		2. Nave S elev, door jamb	570-610	282 ±58; ±118
All Saints Church, Brixworth	Bx	2. Tower, S elev.	late C8th	215 ±65; ±115
		3. S arcade.		70 ±75; ±130
		8. Nave, W doorway		75 ±75; ±125
		9. Nave/Tower, triple opening		40 ±85; ±140
		15. Choir, N blocked doorway		30 ±120; ±160
Holy Trinity Church, Colchester	343	2. Int. jambs, W doorway	850-950	40 ±85; ±135
St Margaret's Church Darenth	342	1. Nave, NE quoin	980-1060	257 ±68; ±117
St Margaret's Church, Lower Halstow	344	2. Chancel, S elevation.	1010-1060	325 ±85; ±125
St Martin's Church, Chipping Ongar	363	1a. Nave, doorway S elevation	1075-1150	1060 ±37; ±64
		1b. "		1011 ±39; ±68
		2a. Chancel, N elevation		1025 ±25; ±61
		3. Chancel, SE quoin		1005 ±23; ±58
Holy Trinity Church, Bradwell juxta Coggeshall	357	1. Nave, Jamb S doorway	1100-1150	1038 ±28; ±60
St Andrew's Church, Boreham	355	1. Chancel/tower quoin, N respond	?1100-1200	896 ±33; ±68
Coggeshall Abbey (Infirmary), Coggeshall	327	3. Infirmary, pillar	1130-1150	1144 ±30; ±58
Maldon Moot Hall, Maldon	353	1. Base, brick newel staircase	1420-1440	1385 ±18; ±37
Nether Hall, Roydon	326	3. Base, brick newel staircase	1447-1467	1478 ±21; ±34
		4a. "		1438 ±30; ±42
		4b. "		1448 ±30; ±42
		5.		1439 ±25; ±38
Layer Marney Tower, Colchester	325	1. E Tower, gatehouse, 1st	1510-1525	1447 ±20; ±35
St Michael's Church, Woodham Water	338	1. Belfry, 2nd stage, W elev.	1562-1564	1505 ±14; ±29
Eastbury Manor House, Barking, Essex	340	1. Cellar	1557-1577	1545 ±16; ±33
		2. 1st floor, SW room		1522 ±18; ±30
		3. 1st floor, NE room		1538 ±15; ±32
		4. Cellar		1508 ±15; ±30
		5. 1st floor, SW room		1490 ±18; ±32
		6. 1st floor, NE room		1491 ±15; ±30
		7. Attic		1478 ±19; ±33
St Andrew's Church, Earls Colne	339	1. Tower, 2nd Stage	1450-1525	1407 ±16; ±35

Table 3.

Building	Lab. ref.	$D_\beta+D_{ig}$ %	$D_{\gamma+cos}$ %	D_{tot} mGy/a	Dr corr ?	D_e (mGy)
St Martin's Church, Canterbury	345-1	74	26	3.31±0.08	N	6427±85
	-2	79	21	3.47±0.10	Y	5984±106
All Saints Church, Brixworth	Bx-2	73	27	3.82±0.13	Y	6838±86
	-3	73	27	3.42±0.12	Y	6616±80
	-8	70	30	3.51±0.13	Y	6776±104
	-9	72	28	3.45±0.13	Y	6790±169
	-15	70	30	3.40±0.13	Y	6720±315
Holy Trinity Church, Colchester	343-2	72	28	3.38±0.13	Y	6650±63
St Margaret's Church Darenth	342-1	71	29	3.60±0.13	Y	6330±74
St Margaret's Church, Lower Halstow	344-2	70	30	3.33±0.12	Y	5590±190
St Martin's Church, Chipping Ongar	363-1a	78	22	3.14±0.12	Y*	2980±39
	-1b	79	21	3.08±0.11	Y*	3076±39
	-2a	79	21	2.91±0.07	N	2861±30
	-3	71	29	3.06±0.07	N	3070±23
Holy Trinity Church, Bradwell juxta Coggeshall	357-1	71	29	3.15±0.08	N	3060±37
St Andrew's Church, Boreham	355-1	68	32	2.56±0.07	N	2844±43
Coggeshall Abbey (Infirmary), Coggeshall	327-3	81	19	3.39±0.09	N	2925±56
Maldon Moot Hall, Maldon	353-1	65	35	3.07±0.08	N	1887±21
Nether Hall, Roydon	326-3	60	40	3.00±0.08	N	1590±46
	-4a	62	38	3.20±0.09	N	1825±85
	-4b	62	38	3.32±0.09	N	1859±88
	-5	60	40	2.96±0.08	N	1688±59
Layer Marney Tower, Colchester	325-1	64	36	2.93±0.08	N	1641±41
St Michael's Church, Woodham Water	338-1	58	42	2.84±0.08	N	1428±9
Eastbury Manor House, Barking, Essex	340-1	66	33	3.06±0.08	N	1419±57
	-2	62	38	2.69±0.07	N	1307±26
	-3	61	39	2.53±0.07	N	1186±42
	-4	62	38	2.59±0.07	N	1294±20
	-5	63	37	2.64±0.07	N	1365±32
	-6	62	38	2.53±0.07	N	1307±14
	-7	62	38	2.32±0.06	N	1229±29
St Andrew's Church, Earls Colne	339-1	63	37	2.55±0.07	N	1530±12

Notes to Table 3

1. Measurement uncertainties are given at the 68% level of confidence (1σ).
2. The internal grain (α, β) and external grain (β) dose rate, $D_{\beta}+D_{ig}$, and the γ and cosmic dose rate, $D_{\gamma+cos}$, are given as % contributions to the total dose rate, D_{tot}.
3. An indication is given whether the dose rate was assessed for more than one phase arising from reuse or alteration of the structure where the brick is in a primary context. To assess the total dose rate for re-used bricks (342-1, 344-2, 345-2 and all Bx) in their primary contexts, it was assumed that the sampled volume of the brick was originally located 10 cm beneath the outer layer of a wall of at least 50cm thickness and that the wall fabric in the vicinity of the brick comprised 50% brick, 25% mortar and 25% stone rubble. The total dose rate was obtained by calculating the time-weighted average of the dose rate in the primary context and in the sampled secondary context, with an assigned overall uncertainty of ±20% in the gamma dose rate during the estimated first period of use. In these cases the change to D_{tot} corresponded to an average increase of 1.6%. For samples 363-1a&b, a modified dose rate (Y*) was applied to account for blocking the doorway in 1884; before which the gamma dose rate, D_{γ}, was estimated to be 7% and 4% lower, respectively, corresponding to reductions in D_{tot} of 1.5% and 1%. The effect of the infilling of the doorway on the gamma dose rate was calculated using a radiation transport simulation model.

Figure 1.

The locations of the sampled buildings, indicated within an outline map of eastern England: 1. Canterbury (St Martin); 2. Brixworth (All Saints); 3. Colchester (Holy Trinity); 4. Darenth (St Margaret); 5. Lower Halstow (St Margaret); 6. Chipping Ongar (St Martin of Tours); 7. Bradwell-juxta-Coggeshall (Holy Trinity); 8. Boreham (St Andrew); 9. Coggeshall; 10. Maldon (Moot Hall); 11. Roydon (Nether Hall); 12. Earls Colne (St Andrew); 13. Layer Marney Towers; 14. Woodham Walter (St Michael); 15. Barking (Eastbury Manor); 16. Boston (St. Mary's Guildhall); 17. Doddington Hall; 18. Tattershall Castle; 19. Spalding (Ayscoughfee Hall).

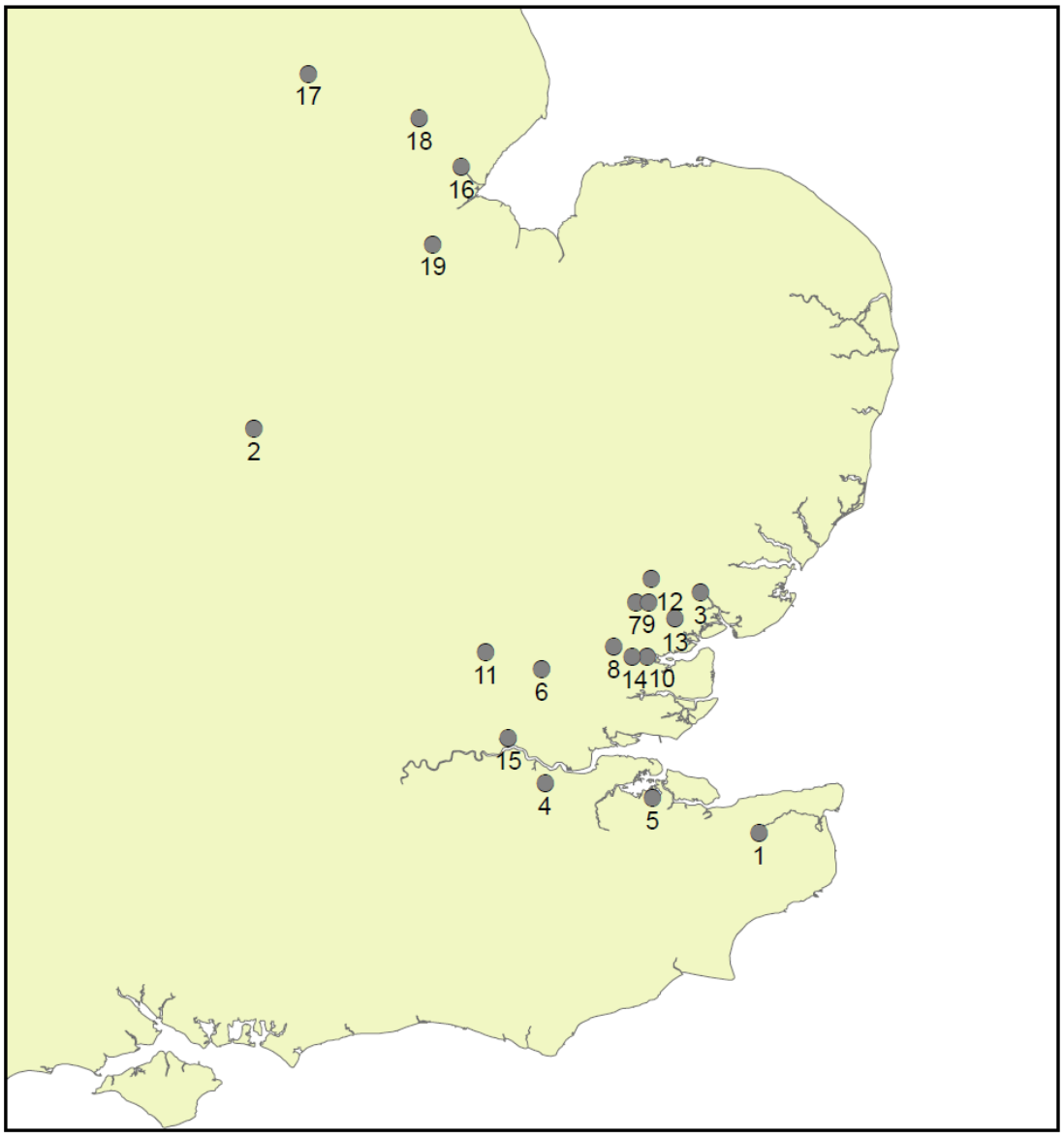
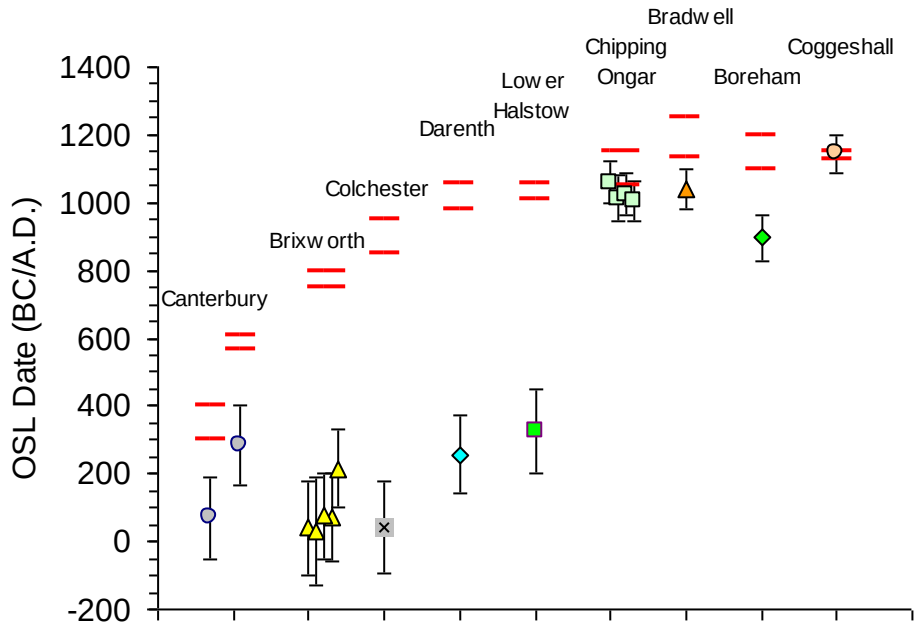


Figure 2.

Individual OSL dates grouped according to assigned date range: a) Sixth – thirteenth centuries AD and b) Fourteenth-sixteenth centuries AD, where the vertical bars correspond to the overall error ($\pm\sigma_B$). The horizontal bars indicate the upper and lower limits of the assigned date range (Table 2).

a)



b)